Guidance on the Preparation of Exceptional Events Demonstrations for Stratospheric Ozone Intrusions

Draft

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U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
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Acronyms

AQS	Air Quality System
CAA	Clean Air Act
CFR	Code of Federal Regulations
CO	Carbon monoxide, or Colorado
DV	Design value
ENSO	El Nino / Southern Oscillation
EPA	Environmental Protection Agency
FLEXPART	FLEXible PARTicle dispersion model
FR	Federal Register
FT	Free troposphere
GOES	Geostationary Operational Environmental Satellite
HYSPLIT	HYbrid Single-Particle Lagrangian Integrated Trajectory
IDEA	Infusing Satellite Data into Environmental Applications
IPV	Isentropic potential vorticity
K	Kelvin
km	Kilometer
LIDAR	Light detection and ranging
mb	Millibar
NAAQS	National ambient air quality standard or standards
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NO	Nitric oxide
NOx	Nitrogen oxides
NWS	National Weather Service
OMI	Ozone monitoring instrument
PBL	Planetary boundary layer
PM	Particulate matter
ppb	Parts per billion
PT	Potential temperature
RAQMS	Real-time Air Quality Modeling System
RH	Relative humidity
VOC	Volatile organic compound or compounds
Z	Zulu (time; same as Greenwich Mean Time)

1. Overview

1.1 Statutory and Regulatory Requirements

The Environmental Protection Agency (EPA) promulgated the Exceptional Events Rule in 2007[1] to implement the statutory requirements in Clean Air Act (CAA) section 319(b). This section of the CAA allows the governor of a state to petition the EPA Administrator to exclude air quality monitoring data that is directly due to exceptional events from use in determinations by the Administrator with respect to exceedances or violations of the national ambient air quality standards (NAAQS). After engaging in a public notice-and-comment rulemaking process, in September of 2016,[2] the EPA promulgated revisions to the 2007 Exceptional Events Rule to address certain substantive issues raised by state, local and tribal co-regulators and other stakeholders since promulgation of the 2007 rule and to increase the administrative efficiency of the Exceptional Events Rule criteria and process.

The revisions at 40 CFR 50.14(c)(3)(iv) and (v) identify the following required elements and technical criteria that air agencies[3] must include in their exceptional events demonstrations:

- A *narrative conceptual model* that describes the event(s) causing the exceedance or violation and a discussion of how emissions or transport from the event(s) led to the exceedance or violation at the affected monitor(s)
- A demonstration that the event affected air quality in such a way that there exists a *clear causal relationship* between the specific event and the monitored exceedance or violation, supported by analyses that compare the claimed event-influenced concentration(s) to concentrations at the same monitoring site at other times unaffected by events
- A demonstration that the event was both *not reasonably controllable and not reasonably preventable*
- A demonstration that the event was a *human activity* that is unlikely to recur at a particular location *or was a natural event*
- Documentation that the submitting air agency followed the *public comment process*

As identified in 40 CFR 50.14(c)(2), air agencies should also contact their EPA regional office soon after identifying event-influenced data that potentially influence a regulatory decision and/or when an agency wants the EPA's input on whether or not to prepare a demonstration.

1.2 Purpose of this Document

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[1] "Treatment of Data Influenced by Exceptional Events; Final Rule" (72 FR 13560, March 22, 2007).

[2] The EPA has prepared this draft guidance to align with the Exceptional Events Rule revisions finalized on September 16, 2016 (81 FR 68216), and available on the EPA's exceptional events website at *http://www.epa.gov/air-quality-analysis/treatment-data-influenced-exceptional-events*.

[3] The term "air agencies" is used throughout this document to include state, local, and tribal air agencies responsible for implementing the Exceptional Events Rule. In the context of flagging data and preparing demonstrations, the roles and options available to air agencies may also include federal land managers of Class I areas and other federal agencies that either operate monitors affected by an event or that manage federal land.

This document is intended to assist air agencies in preparing demonstrations for stratospheric ozone intrusions that meet the requirements of the Exceptional Events Rule revised in 2016 (the 2016 Exceptional Events Rule). This guidance provides example language and sample analyses that air agencies may use to address the elements identified above in demonstrations for stratospheric ozone intrusions. Because this guidance identifies analyses and language to include within an exceptional events demonstration and promotes a common understanding of these elements between the submitting air agency and the reviewing EPA regional office, the EPA anticipates expedited review of demonstrations prepared according to this guidance. Although this guidance provides example analyses that air agencies may use in their demonstrations, air agencies may also use well-documented, appropriately applied and technically sound analyses not identified in this guidance. This guidance does not impose any new requirements and shall not be considered binding on any party.

As appropriate under a weight of evidence approach, air agencies should prepare and submit the appropriate level of supporting documentation, which will vary on a case-by-case basis depending on the nature and severity of the event. This guidance identifies two tiers of analyses for developing evidence for exceptional events demonstrations for stratospheric ozone intrusions. Tier 1 analyses are intended for events that occur when photochemical production of ozone is clearly unfavorable and yet surface ozone concentrations are much higher than normal observations and the synoptic meteorological pattern suggests a stratospheric intrusion may be the cause. These events will require less supporting documentation. Tier 2 analyses are appropriate for events where local photochemical ozone production may exist simultaneously with stratospheric ozone contributions, or for events where the observed ozone is in the range of normal seasonal values at that location. Tier 2 demonstrations will require more supporting analytical documentation than Tier 1 demonstrations.

1.3 Stratospheric Ozone Intrusions

The preamble to the 2016 Exceptional Events Rule identifies stratospheric ozone intrusions as natural events that could qualify as exceptional events under the CAA and Exceptional Event Rule criteria. This section of the guidance provides a brief scientific overview of stratospheric ozone and the exchange processes that enable potential contributions to surface ozone concentrations.

The characteristics and composition of the atmosphere vary with height. When considering the potential impacts of stratospheric ozone at the surface it is instructive to consider three specific atmospheric layers (from highest to lowest): the stratosphere, the free troposphere (FT), and the planetary boundary layer (PBL). The depths of each of these layers are dynamic and can depend on the time of year, the time of day, location, and meteorological conditions. The stratosphere generally extends from 10-15 km above the surface up to an altitude of approximately 50 km (Seinfeld and Pandis, 2006). Temperatures increase with height in the stratosphere. When temperatures increase with height (i.e., a "temperature inversion"), vertical mixing of atmospheric material is limited. As such, the stratosphere is typically a distinct and highly stable layer that interacts minimally with atmospheric layers above and below. The stratosphere also features a large reservoir of natural ozone resulting from the interaction of ultraviolet light and molecular oxygen. Ozone concentrations in the stratosphere can be orders of magnitude larger than what are observed at the surface (i.e., > 5000 ppb). Below the stratosphere is the troposphere, a layer which extends from the surface to 10-15 km. For the purpose of considering stratospheric-tropospheric exchange, it is instructive to subdivide this atmospheric layer into two separate ones (from higher to lower): the FT and the PBL. Both the FT and the PBL are generally well-mixed layers sometimes separated by a temperature inversion (or inversions) that limits transport of material between layers. The depth of the PBL depends on local meteorological conditions but can range from as low as 25 m on cold winter nights, to as high as 5-6 km on warm and dry summer days. While actual atmospheric conditions are typically more complicated than the simple 3-layer structure outlined here, any demonstrations of the causal impacts of stratospheric ozone should describe: 1) how material was transported from the lower stratosphere to the FT, and then 2) how the material was transported from the FT to the PBL.

As discussed above, the temperature inversion that separates the FT from the stratosphere typically limits the transport of stratospheric air into the troposphere. However, in some cases, “ribbons” or “filaments” or “streamers” of ozone-rich air from the stratosphere can be displaced into the FT via a process known as tropopause folding[4] (Holton et al., 1995). These tropopause-folding events frequently occur in conjunction with deepening upper-atmospheric low-pressure disturbances (Danielsen, 1968) and can result in stratospheric air descending deep into the FT. These “intrusions” of stratospheric air have been found to be associated with extratropical cyclones (Wernli and Bourqui, 2002) and, as such, occur more commonly in the winter/spring seasons than the summer/autumn seasons over the U.S. From a spatial perspective, suspected stratospheric intrusions are more common along the west coast of the U.S., although they can occur elsewhere (Langford, et al, 2012). There can be year-to-year variability in the number of tropopause folding events that influence the U.S. depending on global climate features like the El Nino-Southern Oscillation (ENSO) (Lin et al., 2015) and this variability can affect ozone trends (Verstraeten, et al, 2016). Additionally, inversion events can vary in magnitude and spatial extent. Exceptions exist, but they generally range from 200-1000 km in length, 100-300 km in width, and 1-4 km in depth (Wimmers et al., 2003;). Stratospheric ozone can also be assimilated into the FT via other stratospheric-tropospheric exchange processes, such as deep convection (Tang et al, 2011).

Ozone transported into the troposphere by tropopause folding or any other stratospheric-tropospheric exchange process, may remain wholly within the FT or it may be mixed down to the surface. There have been numerous analyses that have shown stratospheric intrusions influencing high surface ozone concentrations at U.S. locations (Langford et al. (2009); Lin et al. (2012); Yates et al. (2013); Zhang et al. (2014); Langford et al. (2015); Knowland et al., (2017)). Stratospheric ozone intrusions are more likely to influence surface concentrations at high elevation sites where less downward movement is needed to affect a surface monitoring site. At these high elevation sites in particular, stratospheric ozone intrusions have been estimated to contribute about 20 to 25 percent of the total tropospheric ozone budget and can cause relatively short-term (i.e., ranging from several hours to 2-3 days in duration) increases of surface ozone of 10 to 180 parts per billion (ppb) above normal background levels (EPA, 2013). Along with high elevation sites, days with very deep PBLs are also more likely to experience stratospheric impacts at the surface as greater amounts of stratospheric-influenced ozone can be captured within the PBL and thermally mixed to the surface.

Because ozone has the same chemical structure whether produced naturally in the stratosphere or troposphere, the source of surface-level, monitored ozone can be difficult to identify.

[4] The tropopause is defined as the boundary between the stratosphere and the free troposphere.

Stratospheric air does, however, have some properties that can be used to distinguish it from tropospheric air. While the troposphere contains varying amounts of ozone, carbon monoxide (CO), NOx, particulate matter (PM) and water vapor, the stratosphere contains large amounts of naturally-produced ozone, as noted previously, and has low concentrations of CO, NOx, PM and water vapor (indicated by low relative humidity). The concurrent impacts on CO and relative humidity, however, can be subtle when stratospheric air has mixed with tropospheric air as the mixing process can dilute the ozone enhancement and increase CO and water vapor concentrations relative to stratospheric conditions. In addition to the chemical and physical identifiers discussed above, isentropic potential vorticity (IPV) and potential temperature (PT) can also be used to help identify the "intrusion" of stratospheric air into the troposphere, as can certain beryllium and lead isotopes. IPV refers to atmospheric spin, which, for stratospheric air, is much higher than for tropospheric air and does not change as it mixes to the surface during intrusions. As a result, the IPV for stratospheric air can be up to two orders of magnitude (100 times) greater than the IPV of tropospheric air. Because IPV can vary by season and latitude, PT, which is also higher in the stratosphere than in the troposphere, can serve with IPV as an indicator of stratospheric air at the surface.

In summary, exceptional events demonstrations should contain analyses that demonstrate the processes by which air of stratospheric origin has been transported from the stratosphere into the PBL. Data or graphics showing correlations between elevated ozone and markers of stratospheric ozone (e.g., low CO, low relative humidity (RH), elevated IPV, higher PT) will be valuable elements of the weight of evidence showing for a stratospheric ozone intrusion exceptional event. We discuss these analyses and potential tools for developing these analyses, as well as our proposed tiering approach (discussed below) for developing demonstrations in the subsequent sections of this guidance document.

1.4 Recommended Process for Submitting an Exceptional Event Demonstration for Stratospheric Ozone Intrusions

The EPA reviews all exceptional events demonstrations with regulatory significance on a case-by-case basis using a weight-of-evidence approach. This means that the EPA considers all relevant evidence submitted with a demonstration or otherwise known to the EPA and qualitatively "weighs" this evidence based on its relevance to the 2016 Exceptional Events Rule criterion being addressed, the degree of certainty, its persuasiveness, and other considerations appropriate to the individual pollutant and the nature and type of event before acting to approve or disapprove an air agency's request to exclude data under the 2016 Exceptional Events Rule. Each event eligible for consideration under the 2016 Exceptional Events Rule will likely have unique characteristics. Therefore, the documentation and analyses that air agencies should include in their demonstrations will vary depending on the nature and severity of the event, the characteristics of the typical ozone concentrations at the affected monitor, and the complexity of the airshed.

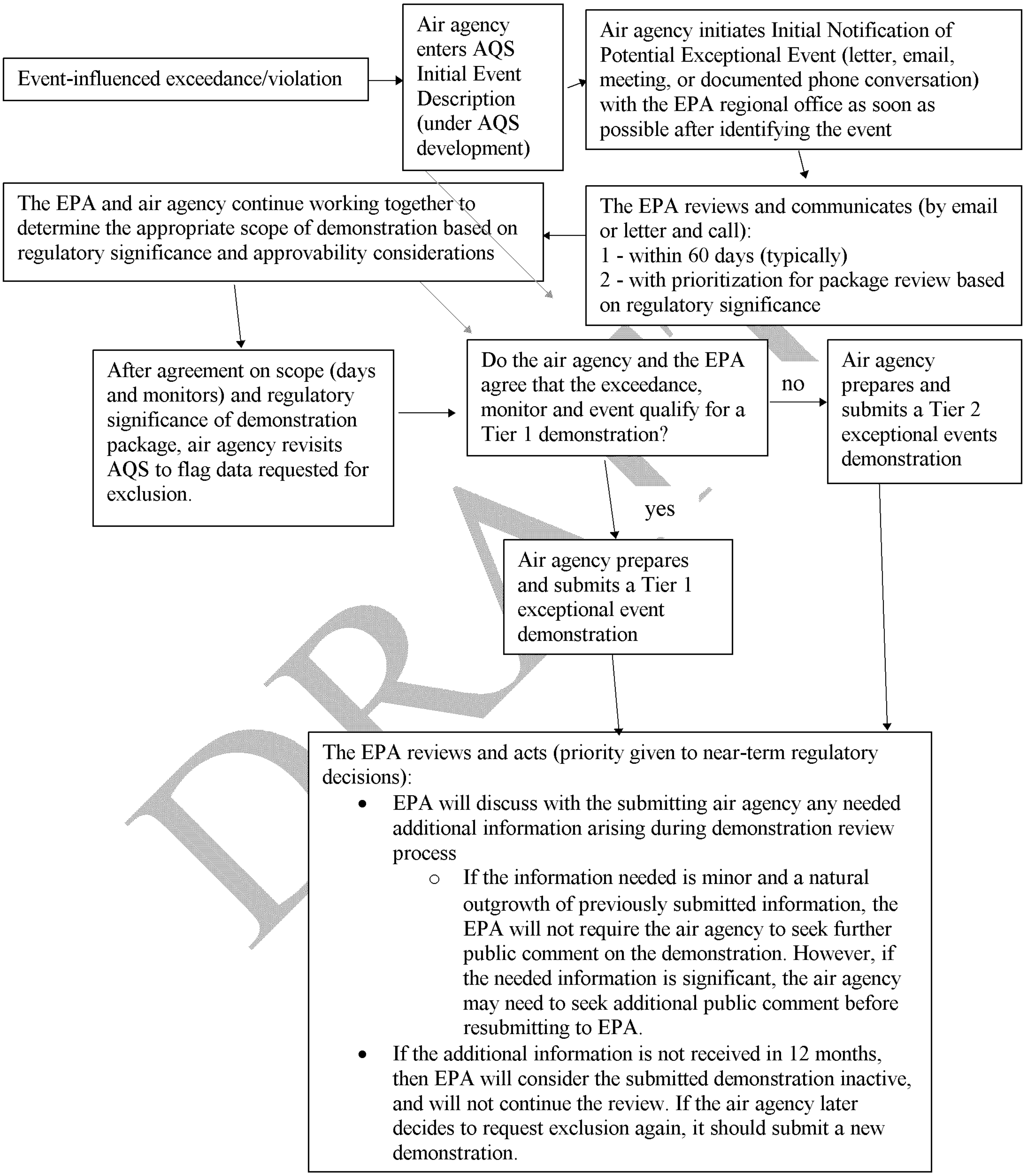
EPA intends to use a tiering strategy consisting of two tiers of demonstrations, to evaluate submittals for stratospheric ozone intrusion events, based on an event's potential for influencing ozone concentrations at a given monitor and the history of non-event ozone concentrations at the affected monitor(s). This strategy recognizes that some intrusion events may clearly stand out from normally occurring ozone concentrations and, thus, may necessitate less supporting evidence to satisfy the rule requirements, particularly for the clear causal relationship element. Within these two tiers of demonstrations, Tier 1 demonstrations are the simplest and least resource-intensive and may be sufficient for stratospheric intrusion events that cause easily-demonstrable ozone impacts during periods in which ozone concentrations are typically low and meteorological patterns are suggestive of potential transport from the stratosphere. Tier 2 demonstrations should be used when the relationship between the subject intrusion and the influenced ozone concentrations is complex and not fully elucidated with the simpler Tier 1 demonstrations. Subsequent sections of this guidance discuss the types of analyses that could be included within each tier.

As indicated in 40 CFR 50.14(c)(2), the "Initial Notification of Potential Exceptional Event," the EPA expects to discuss potential event-influenced exceedances with an affected air agency prior to the air agency preparing and submitting a demonstration. For stratospheric ozone intrusions, this "initial notification" will, in part, focus on observed ozone concentrations and how the subject event compares to the key factors. As a result of this notification, the EPA and the air agency will begin discussion regarding the appropriate tier (Tier 1 or 2) for the event demonstration. Figure 1 provides an overview of the recommended process for preparing, submitting and reviewing exceptional events demonstrations for stratospheric ozone intrusion events.[5]

This guidance document is organized by 2016 Exceptional Events Rule-required elements in the recommended order for inclusion within an exceptional events demonstration. Section 2 covers the narrative conceptual model. Section 3 describes the recommended approach for tiering stratospheric intrusion events and provides guidance for establishing a clear causal relationship between the event and the ozone violations in question. Sections 4 and 5 discuss the additional required elements of an exceptional events demonstration, which are straightforward for stratospheric intrusions, as well as the public comment process.

[5] The exact process order can vary depending on the specific situation.

Figure 1: Flowchart summarizing the EPA's recommended process for preparing, submitting and reviewing exceptional events demonstrations for stratospheric ozone intrusion events.



2. Conceptual Model of Event

2.1 Rule Provisions related to Conceptual Models

The 2016 Exceptional Events Rule revisions at 40 CFR 50.14(c)(3)(iv)(A) require that demonstrations include a conceptual model, or narrative, that describes the event causing the exceedance, discusses how emissions (or transport) from the event led to the exceedance at the affected monitor(s), and identifies the regulatory decision affected by the exceptional event. Because this narrative should appear at or near the beginning of a demonstration, it will help readers and the reviewing EPA regional office understand the event formation and the event's influence on monitored pollutant concentrations before the reader reaches the portion of the demonstration that contains the technical evidence to support the requested data exclusion. The EPA expects that the air agency could include in the conceptual model much of the information that the air agency provided to, or discussed with, the EPA during the initial notification process.

2.2 Elements of a Conceptual Model

A conceptual model is intended to frame the "state of the knowledge" regarding the influence of emissions, meteorology, transport, and/or other relevant atmospheric processes on air quality in an area (McMurray et al., 2004, 2004). A well-constructed conceptual model of ozone formation in the area can assist in the determination of a stratospheric ozone exceptional event by highlighting the contrast between typical, non-event, high ozone days and the event-influenced days in question. The conceptual model should provide a context for the more detailed clear causal analyses described in Section 3. To promote a shared understanding and interpretation of this information, the EPA recommends that the submitting air agency tie the presented evidence and analyses to the narrative conceptual model, which should do the following:

- Provide a map of the existing ozone monitors in the area and a description of the sites (e.g., site ID, current DV, elevation, recent ozone trends), and any other relevant information.
- Note the monitor(s) and days for which the air agency is requesting data exclusion.
- Briefly summarize the processes that lead to high ozone concentrations at the monitor on non-event days. The contents of this summary will vary by area, but could include:
  - the months in which high ozone days usually occur,
  - the diurnal evolution of a typical 8-hour ozone exceedance in the area,
  - typical spatial patterns of ozone on exceedance days, and/or
  - the meteorological conditions often associated with typical high ozone days.
- Introduce the meteorology that caused the stratospheric ozone intrusion and provide a brief narrative for how stratospheric material was transported into the FT and ultimately mixed down through the PBL to the surface monitor.
- Describe the key differences between the observed event-related concentration(s) and a typical, local, non-event ozone exceedance.
- Summarize the affected area's NAAQS attainment and classification information.
- Describe the regulatory determination influenced by the event-related data exclusion. Include a table of the monitor data requested for exclusion (e.g., date, hours, monitor values, and DV calculations with and without the exceptional event).

3. Clear Causal Relationship between the Specific Event and the Monitored Concentration

3.1 Rule Provisions related to the Clear Causal Relationship

The 2016 Exceptional Events Rule revisions at 40 CFR 50.14(c)(3)(iv)(B) and (C) require that an air agency's demonstration to justify data exclusion must include a demonstration that "the event affected air quality in such a way that there exists a clear causal relationship between the specific event and the monitored exceedance or violation" including support from analyses comparing the claimed event-influenced concentration(s) to concentrations at the same monitoring site at other times. In addition to providing the historical context for the event-influenced data, an air agency should also support the clear causal relationship with evidence showing that ozone from the stratospheric intrusion was transported to the monitor.

3.2 Determining the Appropriate Tier for the Event

As introduced in Section 1, EPA recognizes that the "clear causal relationship" between certain ozone exceedances and associated stratospheric intrusions are easily evident. In some cases, the event-caused exceedance occurs outside the normal period in which high ozone is typically observed. In other cases, exceedances caused by stratospheric intrusions occur during times of day, or during meteorological conditions, that are not typically favorable to high ozone (e.g., nighttime, cooler conditions). In other cases, the stratospheric intrusion results in an anomalous spike in ozone concentrations at the monitor that cannot be explained by usual ozone formation processes in the area. When the clear causal relationship is readily apparent, EPA believes that the causality can be demonstrated with a smaller set of analyses than may be required in other cases where the stratospheric contribution is mixed with other sources that may also be contributing to the exceedance. A similar tiering process is recommended in EPA's guidance on wildfire events that may influence ozone concentrations (EPA, 2016).

As discussed in Section 1, the EPA expects to discuss potential event-influenced exceedances with an affected air agency prior to the air agency preparing and submitting a demonstration. As a result of this discussion, the EPA and the air agency will jointly identify the appropriate tier (Tier 1 or 2) for the event demonstration. While each stratospheric exceptional event demonstration will involve a unique set of conditions, EPA believes that the general criteria listed below would suggest a Tier 1 demonstration to be appropriate:

- Meteorological analyses suggest intrusion was recent, nearby and expansive, e.g., associated with a frontal passage and with elevated ozone observed across a large region.
- Resulted in an ozone values clearly distinguishable from usual conditions.
- Occurred outside the period in which high ozone is typically observed.
- Occurred when and where local photochemical production was minimal, e.g, at night, or associated with cold air advection, high wind speeds and/or strong dispersion conditions.

Conversely, these characteristics would suggest the need for a more detailed Tier 2 analysis:

- Resulted from long-distance, multi-day transport requiring detailed analyses
- The event-influenced concentration was in the range of typical exceedances

- Occurred in season when ozone exceedances are historically common
- Occurred in association with other processes and sources of ozone, or on days where meteorological conditions were conducive to local ozone formation (e.g., warm sunshine).

3.3 Comparisons against historical concentrations

The first component of establishing a clear causal relationship between the event and the monitored ozone exceedance is to prepare an analysis showing how the observed event concentration compares to the distribution or time series of historical concentrations measured at the same monitor and/or at other monitors in the area. Air agencies can show the relationship between the event-related concentration(s) and historical concentrations in a variety of ways. Table 1 provides a list of example analyses that could be completed to show that the event-influenced exceedances were outside the bounds of generally expected ozone levels.

Table 1. Possible Analyses for Comparing Historical and Event-Related Ozone

Historical Concentration Evidence	Types of Analyses/Supporting Information
1. Emissions trends	Provide assurance that the area has not experienced significant changes in emissions totals that could invalidate this comparison (e.g., large growth in an important local sector of emissions).
2. Ozone data	Plot the maximum daily 8-hour (or 1-hour) ozone concentration at the affected monitor(s) for the most recent 5-year period[6] that includes the event(s). Can also supplement with a table that briefly describes percentile ranks of event-influenced days and comparisons against historical means and maxima.
3. Identify event influences	Distinguish any high ozone concentrations associated with concurred exceptional events, suspected exceptional events, or other unusual occurrences from high pollution days due to normal emissions (provide evidence to support the identification when possible).
4. Diurnal ozone patterns (*conditional*)	If a tier 1 selection was based on the criteria that the event-related exceedance was measured at an unusual time of day, then show how the diurnal pattern differs due to the event.

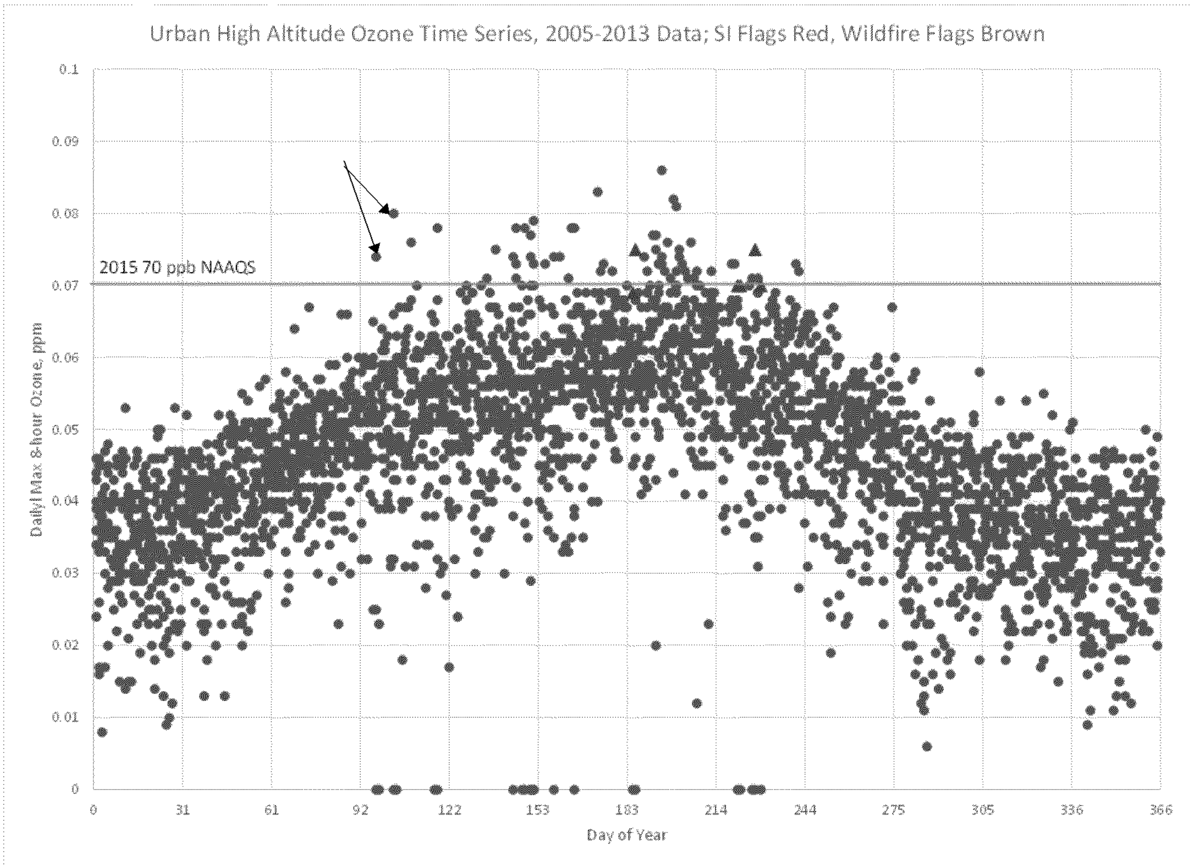
Figure 2 shows an example of a potential plot comparing historical concentrations from non-event days versus days influenced by events[7], including the event days in the demonstration. This sample analysis illustrates nine years of daily peak 8-hour ozone at a single location over all days of the year. The green circles are those days determined to be uninfluenced by exceptional events or unusual occurrences. The brown triangles depict days where wildfire smoke was expected to have

[6] Section 8.4.2.e of appendix W (proposed revisions at 82 FR 5182, January 17, 2017) recommends using 5 years of adequately representative meteorology data from the National Weather Service (NWS) to ensure that worst-case meteorological conditions are represented. Similarly, for exceptional events purposes, the EPA believes that 5 years of ambient air data better represent the range of "normal" air quality than do shorter periods.

[7] This can include events that were never officially determined to be exceptional events.

influenced ozone concentrations. The red circles depict days where stratospheric ozone was expected to have contributed substantially to the observed ozone. In this hypothetical illustration, the black arrows point to the two days in April that are the exceptional events in question.

Figure 2. Sample historical comparison analyses showing how previous non-event days compare against event-influenced days.



When discussing this type of time series plot, describe how the seasonality of the event-related exceedance differs from the typical photochemical ozone season and how other exceedances, if any, during the time of year of the intrusion-related exceedance are not attributable to normal emissions and photochemistry or are clearly lower in magnitude than the intrusion-related concentrations. As part of this discussion, air agencies may also want to prepare similar time series plots for all monitors in the area.

As demonstrated by Figure 2, this example site experiences most of its photochemical ozone exceedances (i.e., not influenced by events) from mid-May through August, with the most frequent exceedances occurring in July. In late May through early June, ozone exceedances can occur with stratospheric intrusions or more typical conditions. However, the rare ozone exceedances observed in April, including those that are the subject of this sample demonstration, are more likely to be influenced by stratospheric impacts and are distinguishable from usual April conditions at the site. In this particular example, the historical comparison would also benefit from some explanation regarding how the two events in question differ from the one case where an exceedance was measured in April (e.g., perhaps that single day featured abnormally summer-like meteorology in April).

Table 2 is a concise summary of the ozone at the site(s) and on the day(s) of the presumed exceptional event and how those data compare to historical values at these locations. As appropriate, this table can include nearby sites and days preceding and following the event if that helps inform the conclusion that something differentiates the event-influenced days from typical observations.

Table 2. Example tabular summary of event-influenced ozone data in parts per billion (ppb) relative to historical concentrations[8]

Statistic	Fruitland	Myton	Whiterocks	Ouray	Redwash	Dinosaur NM	Rangely, CO
Data Years	2011-2015	2011, 2013-2015	2011, 2013-2015	2009-2015	2009-2015	2007-2010, 2011-2015	2010-2015
Number of Samples	1,716	1,316	1,254	2,313	2,279	2,447	1,934
June 8 Max 8-hr Ozone (ppb)	66	71	73	71	74	74	70
June 8 Rank	34 of 1,716	58 of 1,316	18 of 1,254	138 of 2,313	95 of 2,279	51 of 2,447	21 of 1,934
June 8 Percentile	97.9th	95.6th	98.6th	94th	95.8th	97.9th	98.9th
June 9 Max 8-hr Ozone (ppb)	77	72	73	71	72	72	70
June 9 Rank	1 of 1,716	55 of 1,316	19 of 1,254	139 of 2,313	104 of 2,279	54 of 2,447	22 of 1,934
June 9 Percentile	99.9th	95.8th	98.5th	94th	93.9th	97.8th	98.9th
Mean June Daily Max 8-hr O3 (ppb)	48.4	49.7	49.3	51.2	49.8	49.8	45.6
Max June Daily Max 8-hr O3 (ppb)	77	124	107	141	125	126	106
Standard Deviation of June Daily Max 8-hr O3 (ppb)	8.8	12.6	10.1	15.2	12.8	11.9	10.7

3.4 Analyses to Establish a Clear Causal Relationship

The second element in establishing a clear causal relationship between the event and the monitored ozone exceedance is to develop any analyses needed to describe how ozone was transported from the stratosphere to the monitor in sufficient quantities to cause the exceedance. Again, air agencies can describe the mechanics of the stratospheric impact in a variety of ways.

[8] Adapted from "Technical Support Documentation Ozone NAAQS Exceedances Occurring June 8 and 9, 2015 Uinta Basin of Utah". Prepared by: Ute Indian Tribe of the Uinta and Ouray Reservation, U. S. EPA Region 8, Utah State University Bingham Energy Center, and the Utah Division of Air Quality; August 30, 2016.

Based on what is known regarding stratospheric intrusions, it is recommended that a demonstration establish the linkage between the intrusion event and the ozone exceedances in four parts:

- provide a concise overview of the surface ozone and meteorological patterns associated with the event,
- describe which specific meteorological processes resulted in the displacement of stratospheric air into free-troposphere,
- further describe which specific meteorological processes enabled the stratospheric material to reach the surface (Section 3.3.2.3), and
- demonstrate the simultaneous arrival of the stratospheric air with impacts on surface ozone concentrations.

3.4.1 Event Overview

A brief overview of the measured ozone data and the synoptic meteorological pattern that governed the suspected event should be provided near the beginning of a clear causal demonstration. Figure 3a provides an example of a possible graphic that could describe the observed air quality during an event day. Summaries of ozone data (graphical or tabular) on the days immediately preceding and following the event would also be appropriate. For the case[9] depicted in Figure 3a, ozone exceedances were observed over high-elevation portions and generally rural portions of Wyoming, Colorado, and New Mexico. In total, nine sites exceeded the 2015 ozone NAAQS of 70 ppb on this day. The highest recorded value was 82 ppb at the Gothic site in Colorado at an elevation of 2926 m above mean sea level. These exceedances were generally surrounded by lower ozone concentrations in the 50-65 ppb range over the rest of the intermountain western U.S. The high ozone episode was relatively short-lived as there was only one exceedance on the preceding day and no exceedances on the following day in this region. Figure 3b shows an annual time series of daily peak 8-hour ozone at the Gothic site which also depicts the drop off on subsequent days.

[9] For consistency purposes, all the plots in Section 3.4.1 and 3.4.2 of the guidance focus on a particular case (i.e., Saturday April 22nd, 2017 over the Four Corners region of the U.S). While this case is valuable for describing which analyses will be most useful in establishing a clear causal relationship between a stratospheric intrusion event and high observed ozone concentrations, the EPA is making no final judgement on whether these specific case data were impacted by an exceptional event.

Figure 3a. Map of Peak Daily 8-Hour Ozone on April 22, 2017 in the Four Corners region[10]

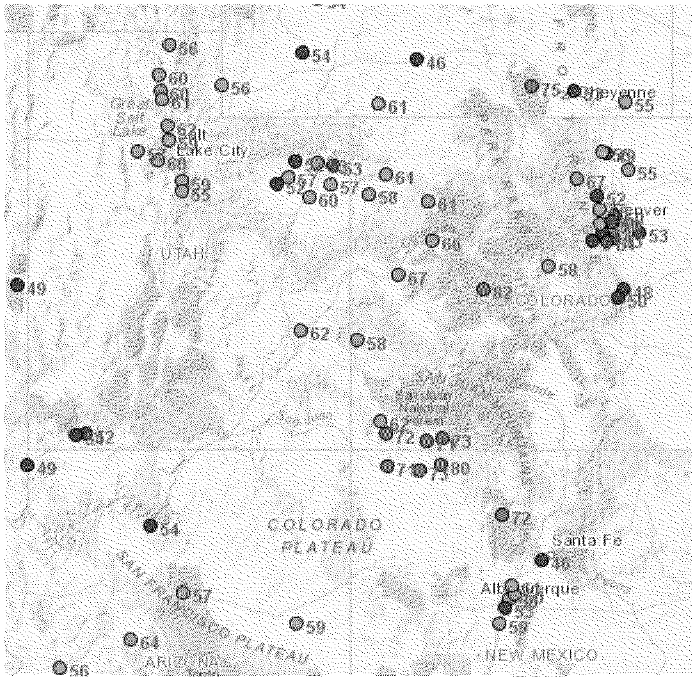
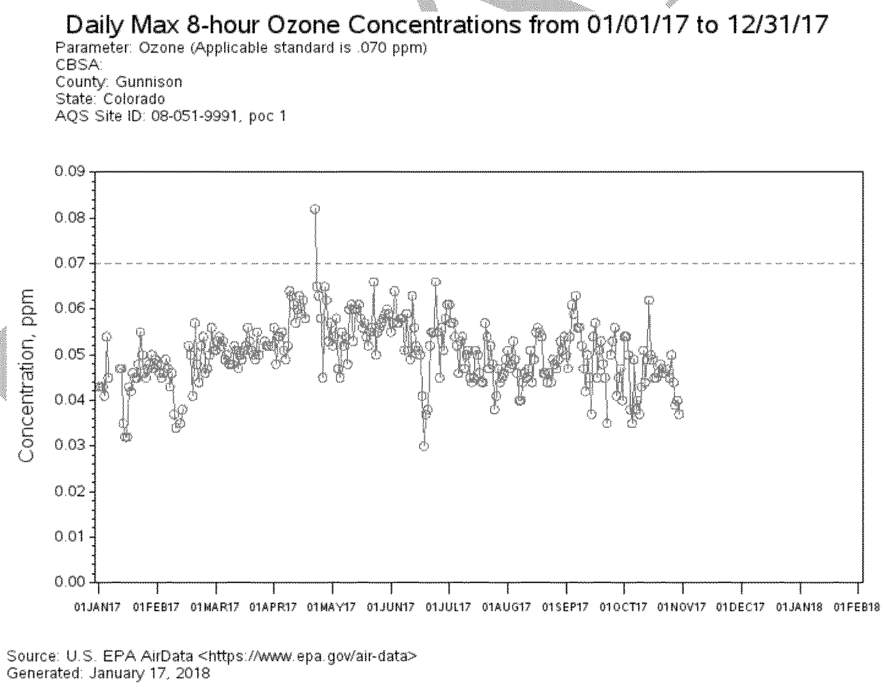


Figure 3b. Time Series of Peak Daily 8-Hour Ozone in 2017 at Gothic Colorado[11]



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[10] This sample map was developed via the Navigator tool on the AirNowTech website: https://www.airnowtech.org/. This site has ozone data archived for periods dating back to the mid-1990's.

[11] Plot was generated at the EPA website: https://www.epa.gov/outdoor-air-quality-data/air-data-concentration-plot. This site has a long archive of ozone data, back into the 1980's if the site has been operational that long.

After providing a description of the observed ozone data, the event overview should briefly describe the key meteorological features that led to the displacement of stratospheric air into the FT. Each intrusion event will be unique, but the following graphics and associated descriptive text would be useful in establishing the basic meteorological context of the event:

- Maps of surface pressure and fronts at a 12-hr frequency (or finer) for the period encompassing the event (i.e., from initiation of the suspected intrusion through the hours in which event-influenced ozone was observed at the surface). In many cases, the patterns associated with a tropopause fold will include a surface cold front passing through the area with cooler dry air advection after the frontal passage. Figure 4a provides an example plot and depicts a case where high pressure had advected into the Four Corners region behind a cold front that moved from north to south through the region on the day before the exceedance. Surface dew point values ranged from 15-20 degrees F on the morning of the exceedance day, indicating very dry air had moved into the region.

- Maps of upper air meteorological conditions at a 12-hr frequency for the period encompassing the event at three different pressure levels: 700 mb, 500 mb, and 300 mb. There are several suitable formats for these types of plots, but in many cases the primary objective would be to show that a substantial trough of low pressure existed upwind or directly over the site in question. Figure 4b provides an example plot and shows streamlines at 300 mb which indicate a neutrally-tilted, but relatively broad trough exists just to the east of the Four Corners region. Higher jet stream winds are measured at the base of the trough. This pattern is favorable for the development of a fold in the tropopause to the west of the trough (i.e., over western WY and western CO).

Wherever possible, these figures should be supported by text that describes the meteorological context and emphasizes the difference between this particular pattern and the weather patterns that are associated with non-event ozone exceedances, per the conceptual model.

Figure 4a. Map of surface pressures and frontal locations 1800Z for sample case day[12]

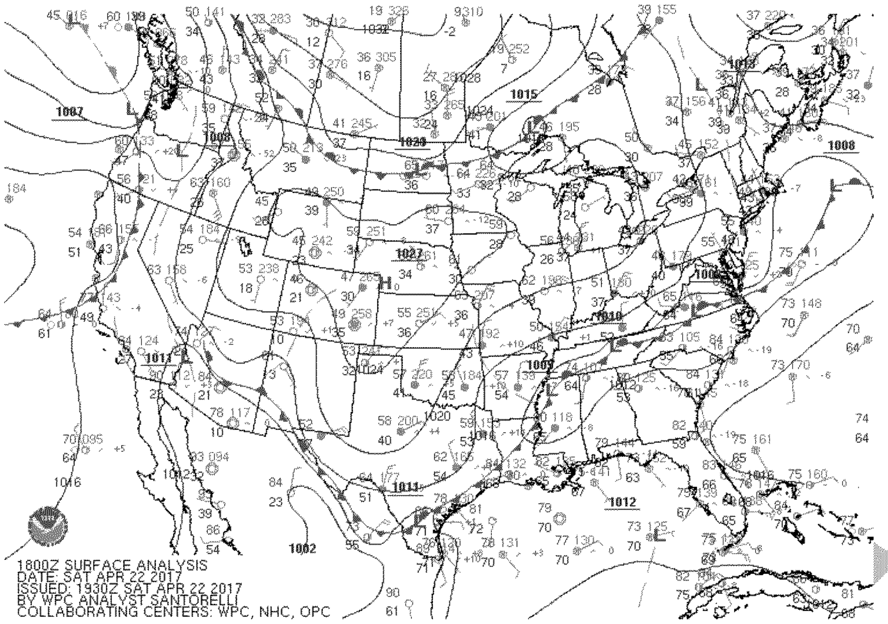
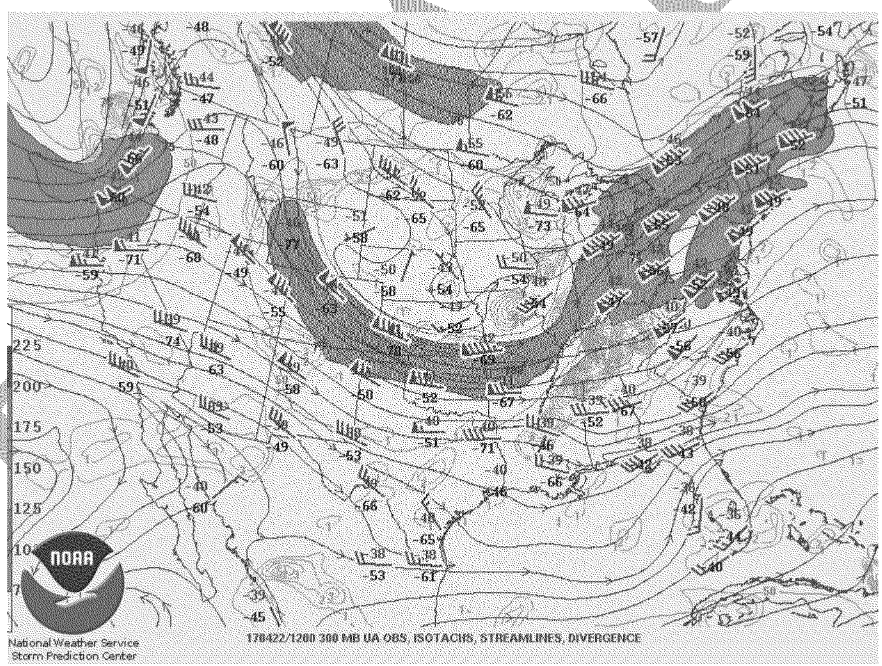


Figure 4b. Map of 300 mb meteorological observations and isotachs for sample case day[13]



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[12] There are numerous sources of surface synoptic meteorological analyses via the internet. This particular plot was accessed from: http://www.wpc.ncep.noaa.gov/archives/web_pages/sfc/sfc_archive.php. At the time this document was written, this site also has an archive of maps dating from the present day to 2005.

[13] There are numerous sources of upper air synoptic meteorological analyses via the internet. This particular plot was accessed from: http://www.spc.noaa.gov/obswx/maps/. This site also has an archive of maps dating from the present day to 1998.

3.4.2 Analyses showing stratospheric-tropospheric exchange

Once a broad overview of the meteorological pattern associated with the event is established, the demonstration can begin to describe the three stages of the intrusion.

- Water vapor imagery: As described in Section 1.3, one of the defining features of the stratosphere is the relative lack of water vapor. Therefore, a stratospheric intrusion will result in deep layers of the FT being drier than usual. Satellite instruments can detect the amount of total column water vapor above the earth's surface. In many stratospheric ozone events, satellite images will show a large expanse of dry air on the back side of the low-pressure trough. This can be broadly symptomatic of a stratospheric intrusion. Figure 5a depicts a scenario in which the aforementioned trough of low pressure has moved east of the Four Corners region. However, the dynamics associated with this system have resulted in a three-dimensional expanse of dry air (as exhibited by darker colors) from western Montana through southern Colorado and into Oklahoma. Note even drier air is located further to the southwest (marked by orange colors). This is likely unrelated to the stratospheric intrusion and is instead due to tropospheric processes.

- Satellite detection of total ozone column data: During a stratospheric ozone intrusion event, the total column of air above the surface will be comprised of a larger-than-normal fraction of stratospheric air relative to tropospheric air. As a result, satellite instruments which detect total ozone column amounts will often exhibit higher-than-average quantities in association with an intrusion. Figure 5b shows the total ozone column data from the Ozone Monitoring Instrument (OMI) on April 21st, 2017. The plot shows a fetch of higher total ozone columns (425-450 Dobson units) stretching from north to south into the Four Corners region. It is important to establish that these total column ozone values are higher than the climatological normal in this region and, therefore suggest that an ozone intrusion has at least made its way from the stratosphere to a portion of the FT.

- Meteorological analyses from a prognostic meteorological or air quality model: Numerous prognostic meteorological model simulations are conducted over the U.S. every day for weather or air quality forecasting purposes. These three-dimensional replications of the atmosphere often contain useful information about the physical state of the air column above the event site that may not have been observed by ambient instruments. Generally, it is better to use model-estimated fields from the initialization state or from a time step near the model initialization (e.g., < 24 hours) to minimize potential for model artifacts. There are a variety of possible products that can help demonstrate that the first stage of an intrusion (stratosphere to FT) occurred. Potentially valuable parameters include: isentropic potential vorticity, tropopause heights or pressures, and/or column estimates of specific stratospheric tracers (CO, RH, N_2O, etc.). Demonstrations of model-estimated Figure 5c shows the model-estimated CO column concentrations in the RAQMS model on April 22nd, 2017. In this example, note the very low concentrations of this stratospheric tracer in the columns above Wyoming, Colorado, and into northern New Mexico associated with the back side of the 300 mb trough. Again, this is complementary evidence that dry, ozone-laden but low CO air has been transported through the tropopause into (at least) parts of the FT.

Figure 5a. Water vapor imagery from the GOES-West satellite from sample case day[14]

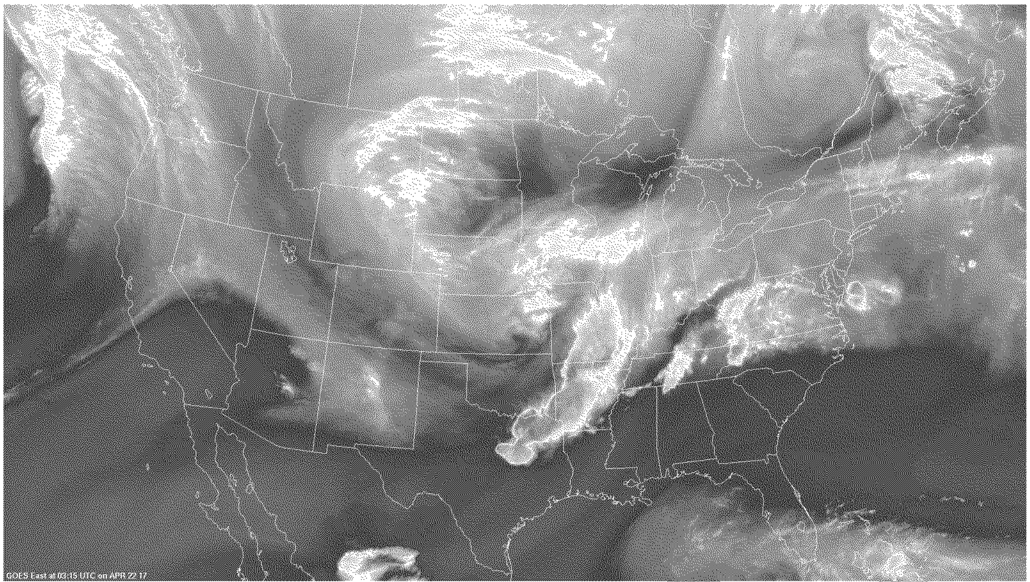

Figure 5b. Map of satellite-estimated total ozone column data from the day before the case event[15]

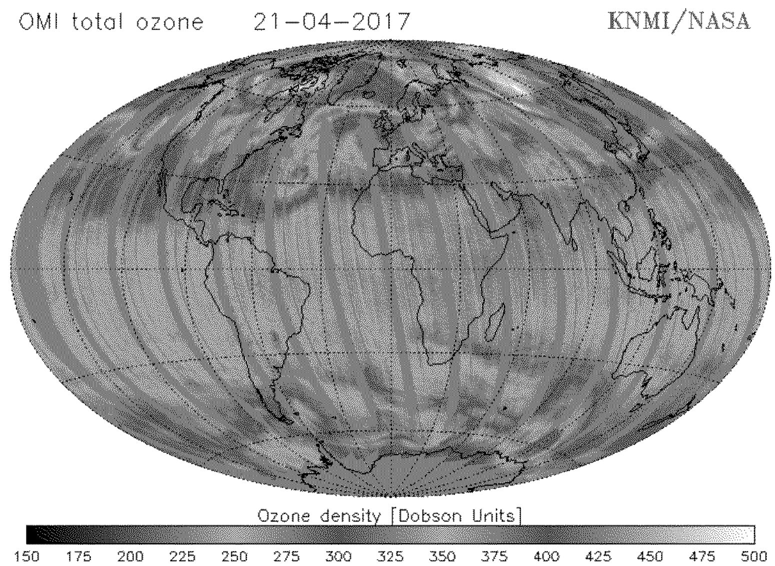

Figure 5c. Model-estimated tropospheric CO column from RAQMS on the case day[16]

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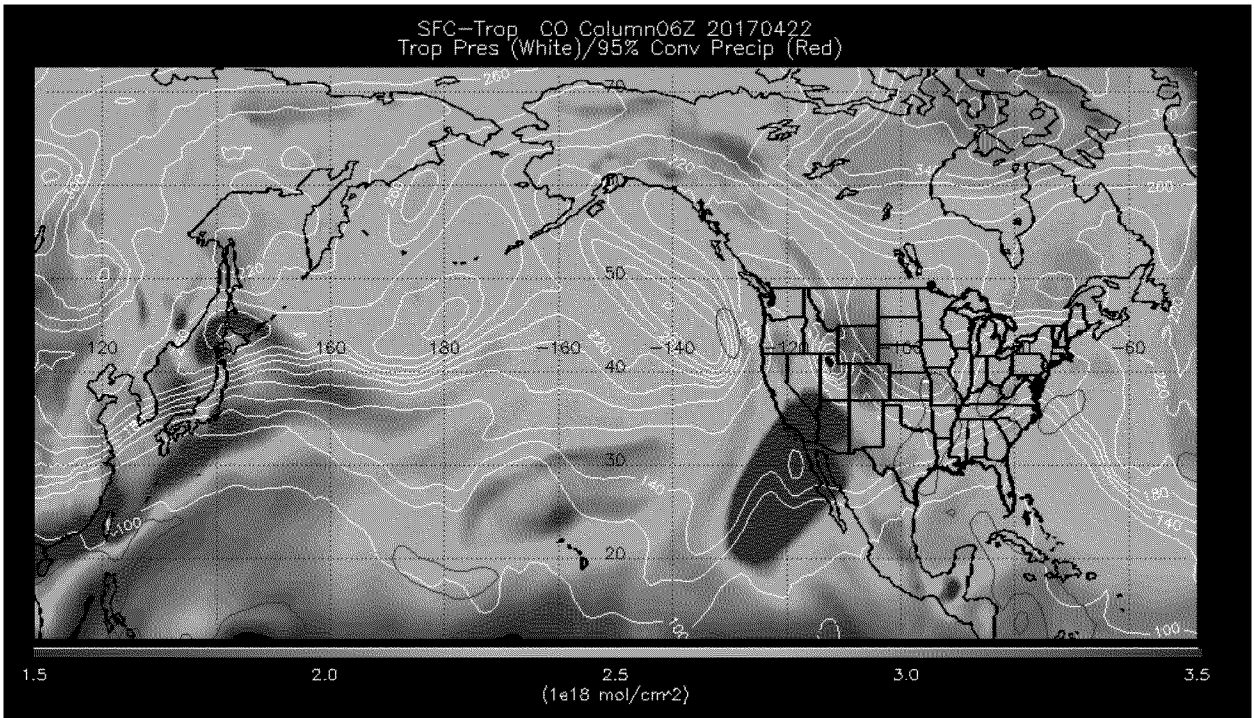
[14] There are numerous sources of water vapor satellite imagery available via the internet, though archived images can be harder to find. Figure 5a was accessed from: ftp://ftp.nnvl.noaa.gov/GOES/color_WV/. Real-time images can be accessed from: http://www.goes.noaa.gov/goes-w/goes-weus-wv.html.

[15] Again, there are numerous potential sources for total column data or products. This particular sample was accessed from: http://www.temis.nl/protocols/O3total.html which has an archive going back to 2004.

[16] This plot was retrieved from the Real-time Air Quality Modeling System archive at: http://raqms-ops.ssec.wisc.edu/previous_products/. Data products exist back to 2010.



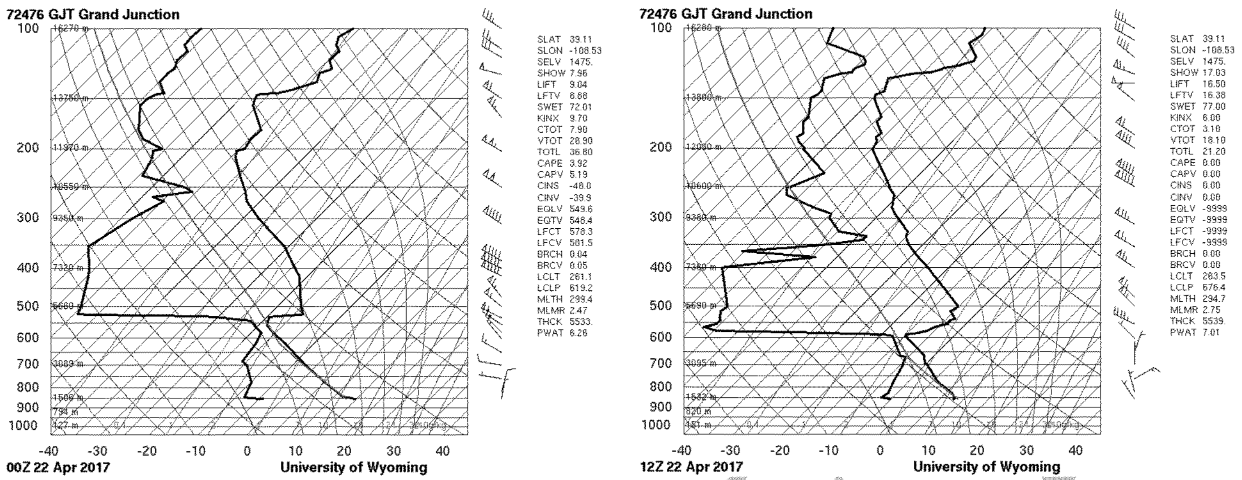
3.4.3 Analyses showing stratospheric air reached the surface

Once it has been established that an intrusion has occurred, the demonstration must show that the stratospheric air was able to penetrate to the lowest levels of the atmosphere (i.e., into the PBL) making surface impacts possible. Many stratospheric intrusions influence the FT but are prevented from reaching the surface due to stable conditions promoted by subsidence inversions or nocturnal boundary layers. Establishing a surface impact typically requires some three-dimensional perspective of the meteorological or chemical state of the atmosphere.

There are a variety of ways in which the vertical composition of the atmosphere can be assessed. The specific analyses best-suited to each individual demonstration will vary depending upon the intrusion event itself and what products are available at a given location.

- A good starting point is to analyze the vertical profiles of temperature and dew point temperatures collected by the twice-daily rawinsonde network. Figures 6a and 6b are "skew-T, log-P" diagrams for two times during the April 22, 2017 event at Grand Junction, Colorado. The figure depicts a large reservoir of dry air above this location at a height of about 5 km above mean sea level, or approximately 3.5 km above the surface at this location. At 0000Z, about 24 hours before the exceedances occurred, there appeared to be a temperature inversion that may have been separating this dry air from lower parts of the troposphere. The same plot from 12 hours later (1200Z) shows that the dry air layer has extended even lower into troposphere by another 500m, such that the dry air is within 3 km of the surface. The temperature lapse rate within the PBL was approximately dry-adiabatic during the afternoon plot (0000Z) which signals that the lower part of the atmosphere was well-mixed during this episode. While these plots are rarely conclusive by themselves, they can provide a "first look" as to the vertical extent of the intrusion.

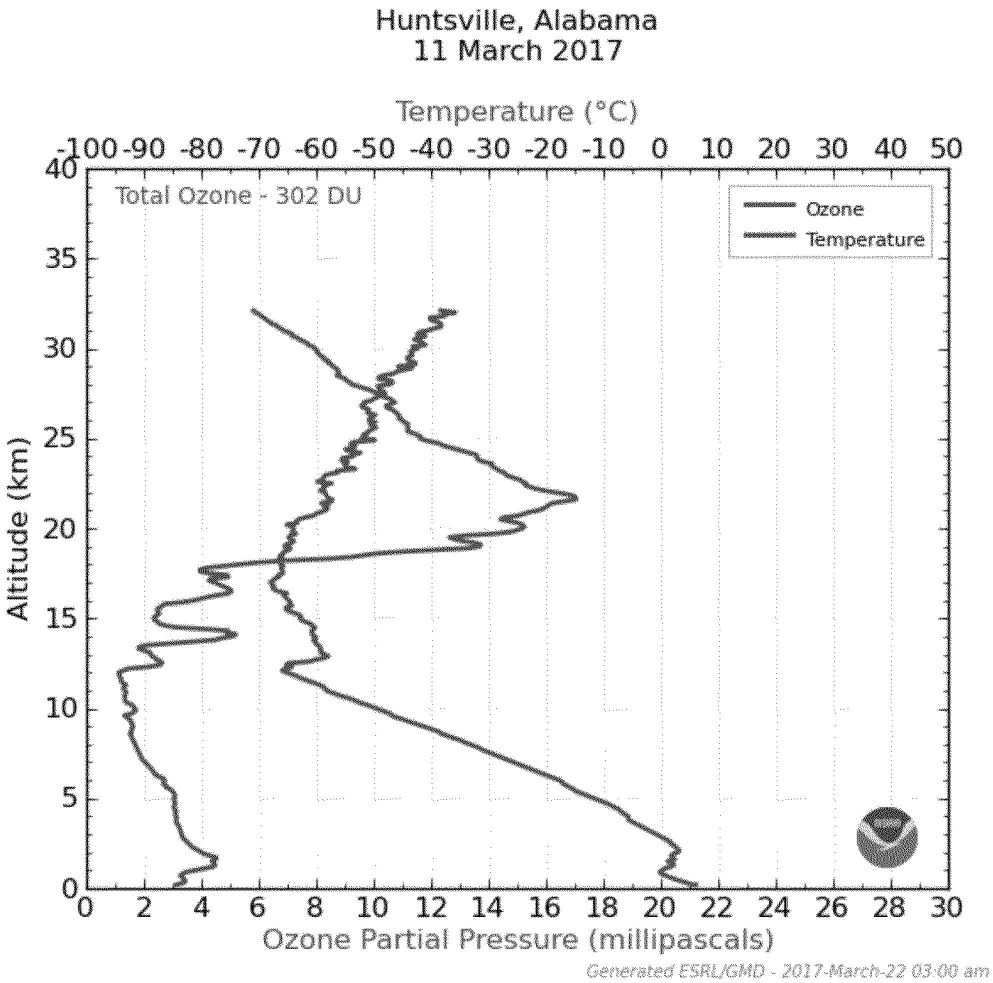
Figures 6a and 6b. Skew-T diagrams for 0000Z (left) and 1200Z (right) April 21, 2017 at Grand Junction, Colorado[17]



- Actual vertical measurements of ozone are the best way to determine whether ozone that originated in the stratosphere has impacted the surface. Unfortunately, the networks that provide these data are relatively sparse and are not often available for the time and location of a suspected stratospheric event. There are multiple possible observational platforms that can be valuable, including: ozonesondes, LIDARs, towers, and instrument-equipped aircraft.
  - Ozonesondes are released into the atmosphere on an infrequent but routine basis at certain locations across the U.S. Figure 6c shows data collected from an ozonesonde launch from Huntsville AL on March 11th, 2017 and is a good example of an elevated ozone layer that does not impact the surface. The plot shows a layer of ozone between 1-2 km of approximately 60-65 ppb (after unit conversion) with a sharp drop off in ozone closer to the surface. Peak 8-hour ozone in Huntsville on this day was 35 ppb, consistent with the ozonesonde data.
  - LIDARs provide highly-resolved ozone data through the lowest layers of the atmosphere (along with other relevant data). Figure 6d shows an example of irregular LIDAR data over a 45-day period near Las Vegas NV. The period is marked by differing patterns of ozone with some days indicative of transport of ozone from the FT into the PBL and others where the ozone formed within the PBL appears to be separated from free tropospheric influence. June 2nd provides a good case study (Langford, et al., 2017) as the LIDAR data suggests that an existing layer of higher ozone at 6-8 km above sea level descends to approximately 4 km above sea level (asl) where it then appears to be mixed down into the PBL and mixes with ozone formed at the surface on both June 2nd and 3rd. A similar situation occurs on May 21st.
  - High-elevation towers equipped with ozone instruments at multiple heights and instrument-equipped aircraft traversing the PBL and FT can also inform a three-dimensional perspective of ozone, but these data are relatively rare.

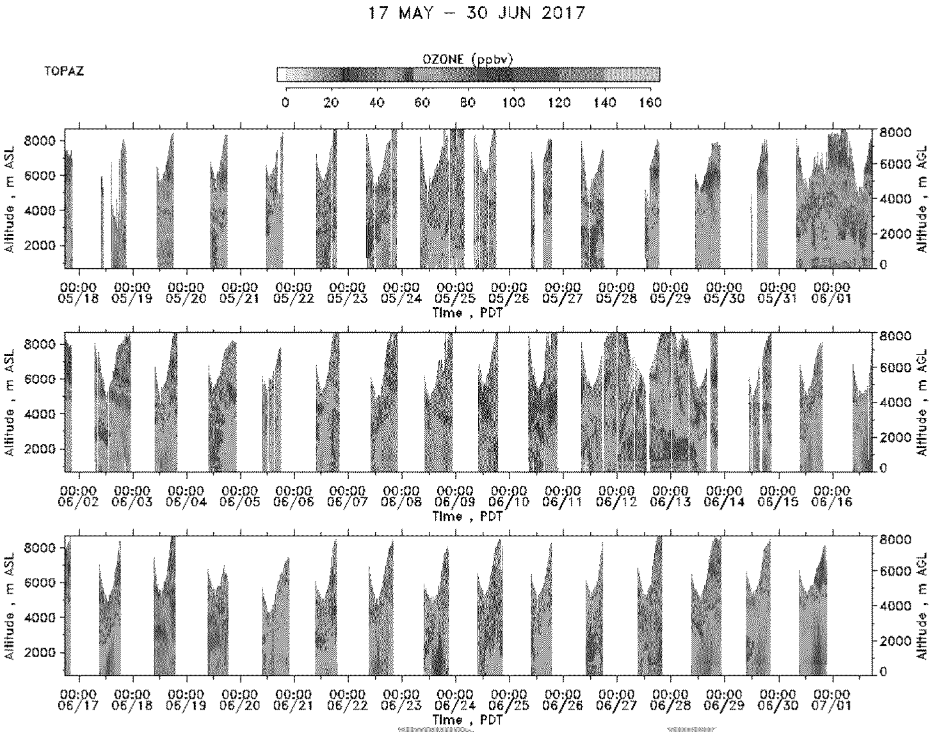
[17] Plots were generated at: http://weather.uwyo.edu/upperair/sounding.html. There are other sources of this information on the internet. Most have archives going back to 1948.

Figure 6c. Ozonesonde data from sample launch from Huntsville AL[18]



[18] This plot accessed from: https://www.esrl.noaa.gov/gmd/ozwv/ozsondes/.

Figure 6d. Time-height ozone cross-sections from LIDAR measurements near Las Vegas



- As in Section 3.4.2, there can also be considerable value in accessing outputs from any available prognostic meteorological or air quality modeling to help demonstrate vertical transport of ozone. For this stage of the determination, the focus should be on how stratospheric ozone, or tracers of stratospheric air are transported from the FT to the PBL. As such, latitudinal or longitudinal cross-sections of model fields can be informative, especially showing how these fields evolve with time. The same meteorological variables discussed earlier can be used to show material may have been exchanged into the PBL (e.g., IPV, potential temperature, water vapor). Increasingly, prognostic air quality model simulations are now archived and available for retrospective analyses of potential exceptional events. Not only can these models provide temporal cross-sections of stratospheric proxies like areas of abnormally low CO concentrations, they can also provide estimates of ozone itself. Any demonstrations that use modeled representations of air quality to show stratospheric transport into the PBL should provide some evidence that the model is well fit for making that determination. Those models that are systematically evaluated daily (and demonstrate relatively low levels of bias and error) are preferable, as are those that assimilate actual air quality data into the simulations. Figure 6e shows a cross-sectional representation of the RAQMS modeled ozone at a latitude of 40 N. The model simulation for 0000Z on April 23rd indicates that 12 hours into the simulation, a lobe of higher ozone has become detached from the stratosphere into the FT, with apparent further mixing down to the surface at specific longitudes (e.g., high elevation at 105W and 112W). (Note: for this particular event, a cross-sectional analysis slightly further south and closer to the surface exceedances would have been more informative.)

- Another potential tool available for demonstrating downward exchange of air masses and source-receptor relationships are trajectory models like HYSPLIT[19]. These models use archived meteorological model initialization data fields to determine how air parcels moved horizontally or vertically to (or from) a given location. Backward trajectories, like the one shown in Figure 6f can help demonstrate possible stratospheric influence into the PBL when they show descending parcels of air originating in the FT but eventually lowering to heights near the surface. Figure 6f suggests that 48 hours prior to the ozone exceedances near Durango CO on April 22nd, 2017, the air mass which eventually settled over Durango was over southern ID at a height of approximately 2.5 km above the ground layer. This air mass descended quickly on the 21st into the PBL before being transported into the Four Corners region on the 22nd. There are several important choices involved in configuring a meaningful HYSPLIT analyses: choice of meteorological model (generally finer-resolution models are better), what surface height to choose (generally best to investigate back trajectories to 100-500 m), what vertical method to use (all three options are worth investigating), and how many hours to simulate (uncertainty increases in analyses longer than 48-72 hours). When using trajectory models to demonstrate potential transport of stratospheric air into the PBL, it is best if multiple model configurations can be tested. Any configurations that are evaluated should be discussed in the demonstration text. Conclusions that are not strongly dependent on model configuration are given greater weight.

[19] There are other trajectory models which can also be used, such as FLEXPART. Also, the IDEA tool is available which computes forward trajectories for locations with high satellite observed ozone.

Figure 6e. Model cross-section of RAQMS-estimated ozone at 0000Z on April 23, 2017

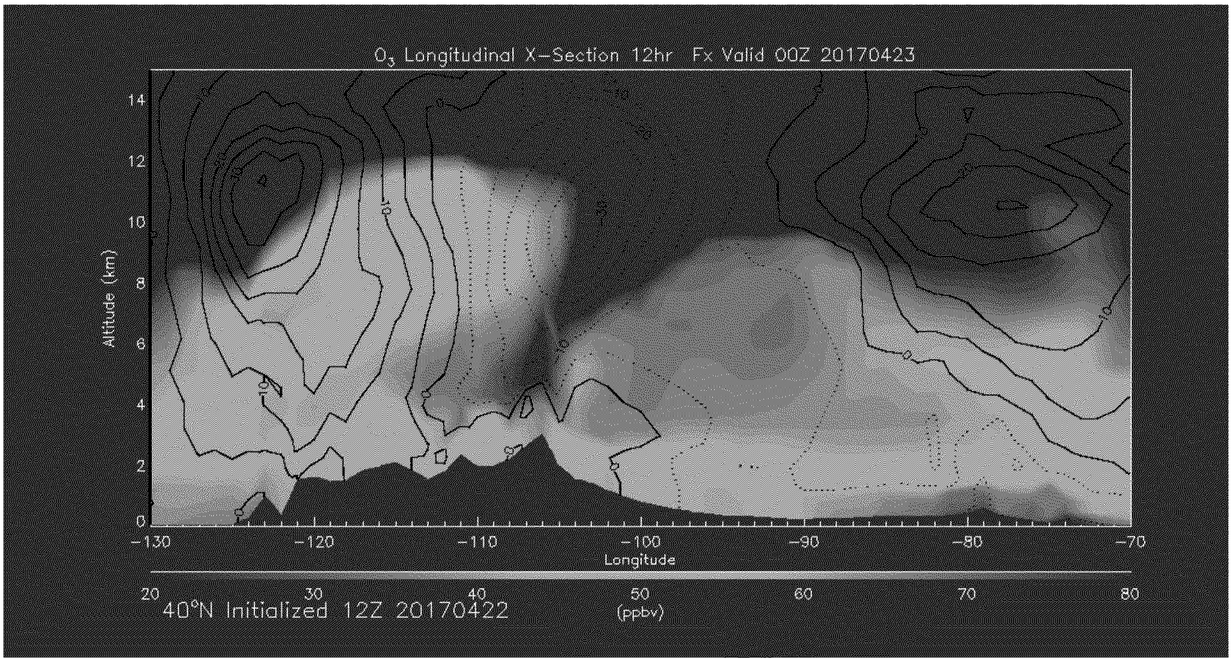
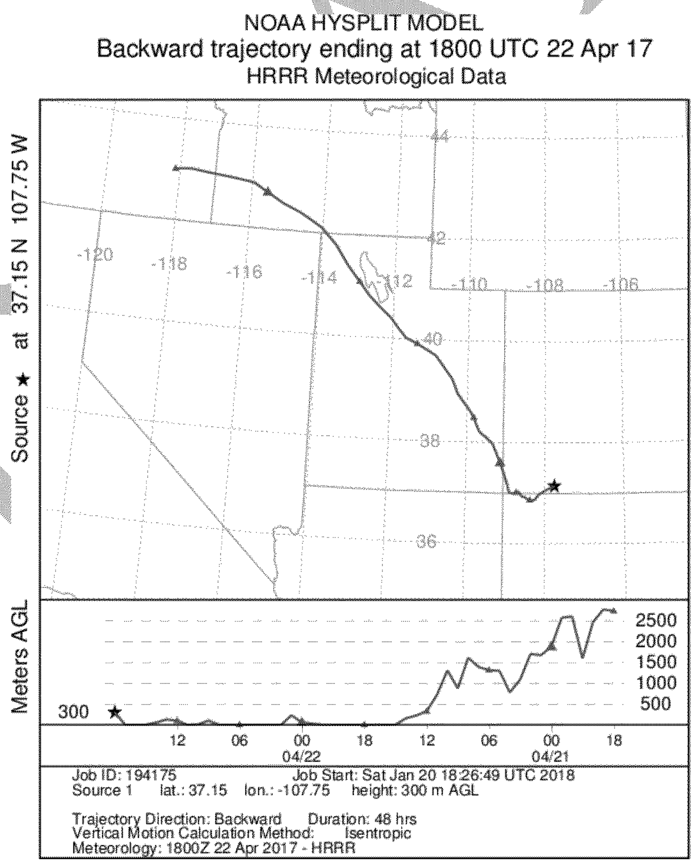


Figure 6f. 48-hour back trajectory from Durango CO on 1800Z April 22, 2017[20]



[20] Trajectories can be generated at: https://ready.arl.noaa.gov/HYSPLIT_traj.php.

3.4.4 Air quality analyses showing the impacts of the intrusion at the surface

Finally, when it has been established that there was an intrusion that over time was able to transport ozone-laden air from the stratosphere into the PBL, the demonstration must then show that the resultant impacts on ozone concentrations measured at the surface caused the exceedance. In some cases, there will be evidence of stratospheric contributions to surface exceedances in conjunction with significant coincident impacts from non-stratospheric sources. These events will be the most challenging to verify and will require the demonstration to clearly describe what differentiates this exceedance from others with similar meteorological, seasonal, or emissions patterns. Ideally, this section of the analysis will be where all the individual elements of the demonstration will be tied together to produce a compelling narrative of a stratospheric ozone exceptional event that falls outside the usual conceptual model of ozone exceedances in the area.

As with the other stages of the analysis, there are a variety of ways in which the causality of the stratospheric intrusion can be gauged. Again, the specific analyses best-suited to each individual demonstration will vary depending upon the intrusion event itself and what products are available at a given location.

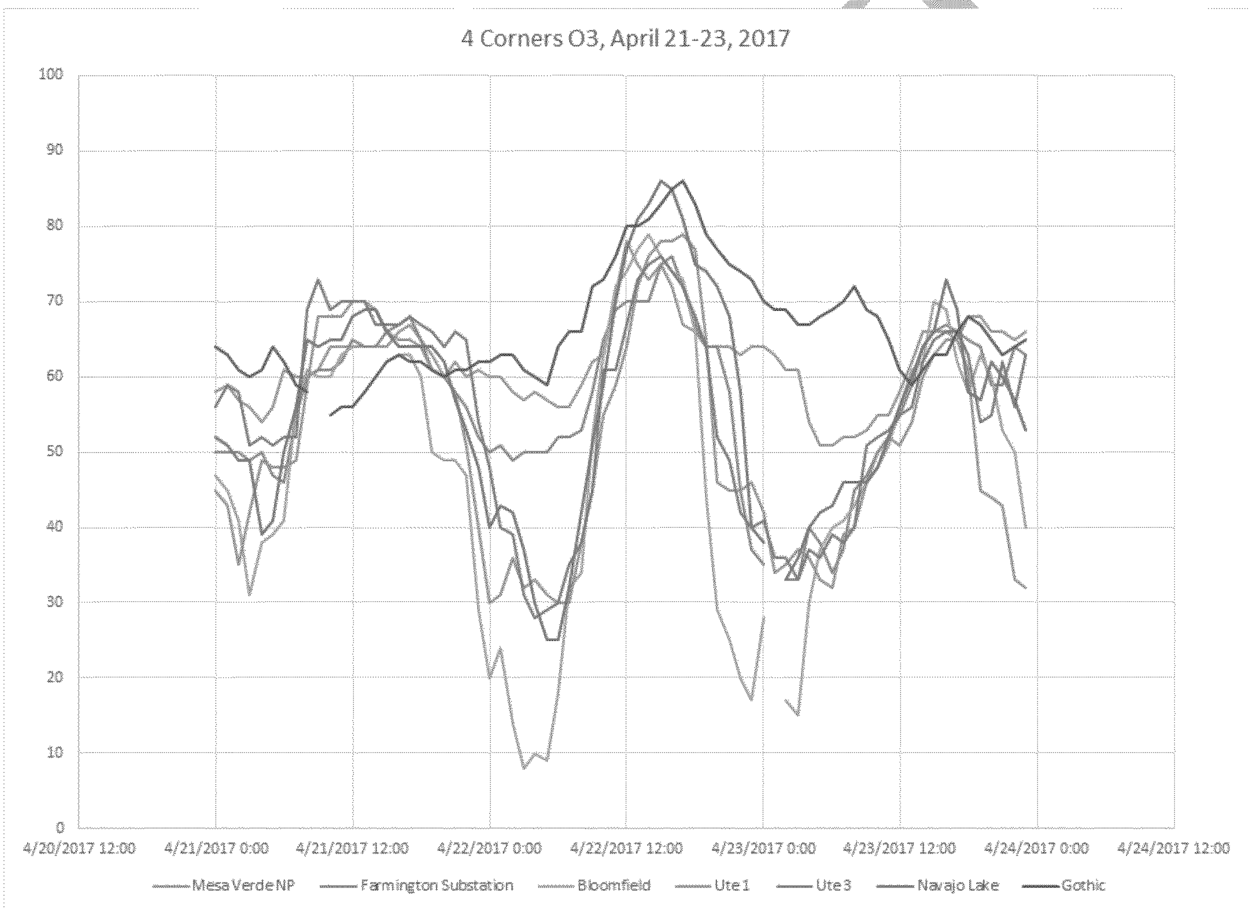
- Evidence that the ozone increases were coincidental with ground-based increases in stratospheric tracers such as, low water vapor, low CO, and/or high concentrations of certain isotopes is the most direct way of showing stratospheric impacts at the surface. Most ozone monitors should have co-located meteorological measurements. Additionally, a few rural high-altitude monitoring sites have both ozone and CO monitors.[21] However, while surface CO measurements may be available, the typical CO monitors used for ambient air monitoring have operational ranges of 500 to 50,000 ppb (0.5 to 50 ppm) and are often not sufficiently sensitive to reliably measure the very low CO levels found in stratospheric air (50 to 150 ppb). The EPA urges air agencies to provide concurrent readings of ozone and CO and/or relative humidity in their exceptional events demonstrations if they have these data. As discussed in Section 1.3, there are two potential beryllium tracers of stratospheric air, specifically: beryllium isotopes Be-7 and Be-10. These elements are produced primarily in the stratosphere by cosmic ray collisions with atmospheric gas atoms and can confirm the presence of stratospheric ozone in surface air (Cristofanelli, 2006). These measurements are, however, rare, expensive and, consequently, not normally available. Where available, vertical profiles of these tracer species measurements may more clearly indicate the presence of stratospheric air at the earth's surface than some of the analyses previously discussed. If any of these data/analyses are readily available, the EPA encourages their inclusion in a demonstration.

- Time series of ozone data can be strong indicators of causal ozone impacts when the rates of hourly ozone increases are synchronized with meteorological evidence from section 3.4.3 of a stratospheric intrusion into the PBL. This type of analysis can take many forms, but usually starts with a time series plot of hourly ozone across the network as per the example in Figure 7a. Based on the analyses discussed above, there is evidence that a tropopause fold occurred in association with a mid-latitudinal trough that traversed the western U.S. from April 20th

[21] A recent review of AQS data revealed 216 sites in the United States with collocated ozone and carbon monoxide monitors in operation after January 1, 2014. Most of these sites are located in either urban or suburban locations. In these settings, local emissions would likely hide the stratospheric CO suppression.

through the 22nd and was likely able to penetrate the lowest layers of the atmosphere over UT, WY, CO, and NM late in the day on the 21st, or perhaps early on the morning of the 22nd. This narrative is supported by the ozone time series at the high-elevation Gothic CO site which shows an increase in ozone from 60 ppb around 0600 local time to about 80 ppb by 1200 local time. This early morning rate of rise is not symptomatic of local photochemical ozone production and precedes similar ozone increases at nearby lower-elevation sites by a few hours. When this time series information is coupled with surface meteorological and/or air quality information that suggests ozone is rising despite a post-frontal transition to a less-photochemically conducive airmass (e.g., cool temperatures, gusty winds, low humidity, low concentrations of CO, PM, or NOx, etc.), this can be compelling evidence of a causal relationship between the intrusion and the exceedance.

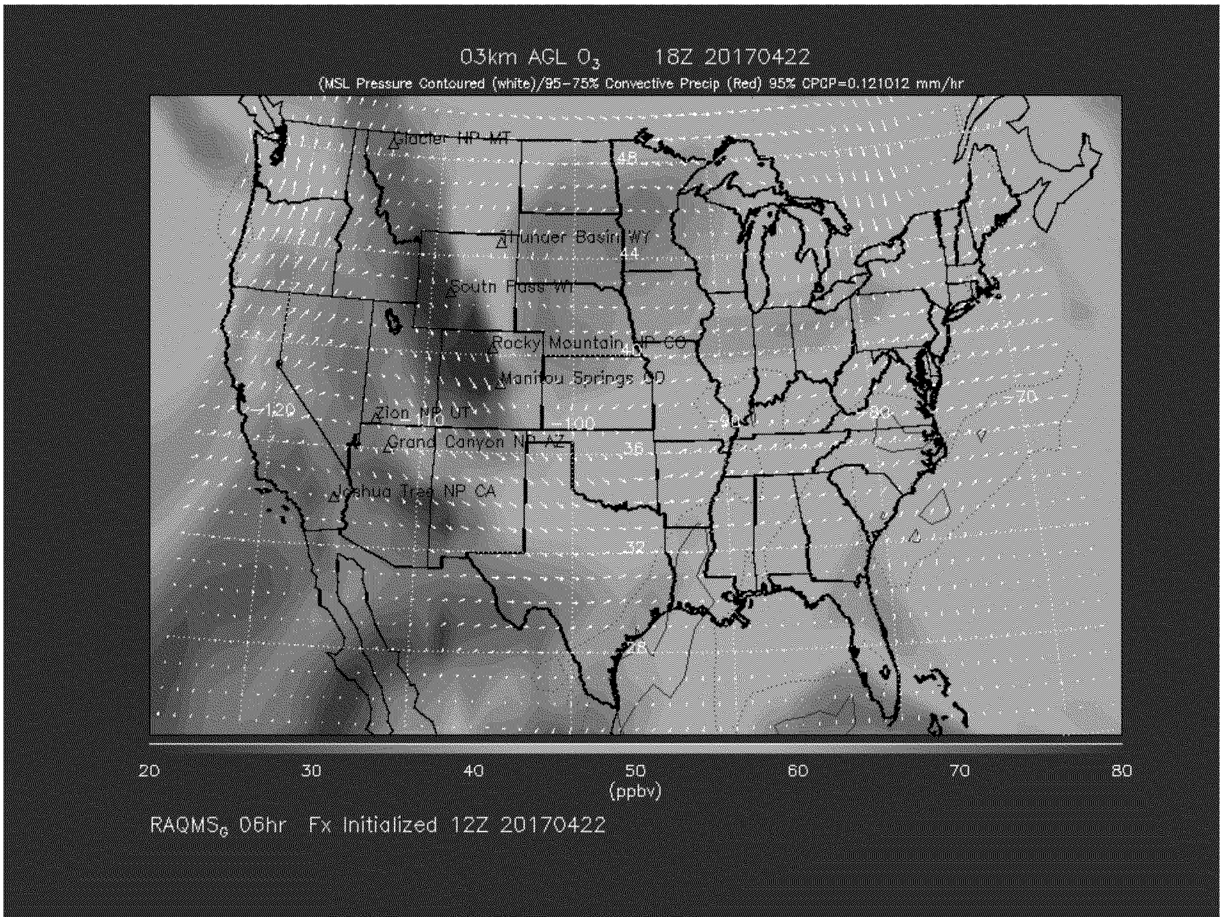
Figure 7a. Time series of ozone at sites in the Four Corner region on April 21-23, 2017



- Comparisons between ozone concentrations on meteorologically similar days with and without stratospheric intrusion impacts could support a clear causal relationship between the subject and the monitored ozone concentration. Ozone formation and transport are highly dependent upon meteorology, therefore a comparison between ozone on meteorologically similar days with and without stratospheric intrusion impacts could provide additional support for event causality. Both ozone concentrations and diurnal behaviors on days with similar meteorological conditions can be useful to compare with days believed to have been impacted by the intrusion. Since similar meteorological days are likely to have similar ozone concentrations, significant differences in ozone concentrations among days with similar meteorology may indicate influences from non-typical sources. Meteorological variables to include in a "matching day" analysis should be based on the parameters that are known to strongly affect ozone concentrations in the vicinity the monitor location (i.e., from the conceptual model). These variables could include: daily high temperature, hourly temperature, surface wind speed and direction, upper air temperature [such as at the 850 or 500 millibar height], relative or absolute humidity, atmospheric stability, cloud cover, solar irradiance, and/or others as appropriate (Eder et al., 1993; Eder et al., 1994; Camalier et al., 2007). Air agencies should match these parameters within an appropriate tolerance. Since high ozone days may be relatively rare, air agencies should examine several years of data for similar meteorology versus restricting the analysis to high ozone days only. The complete range of normal expected ozone on similar meteorology days will have value in the demonstration. A similar day analysis of this type, when combined with a comparison of the qualitative description of the synoptic scale weather pattern (e.g., cold front location, high pressure system location), can help show that the intrusion potentially caused the elevated ozone concentrations. Air agencies may also want to consider non-meteorological factors such as choosing days with similar, non-event emissions (possibly avoiding holidays and special public events, weekend versus weekday mismatches, and any other days with unusual emissions).

- Prognostic or retrospective air quality models may be used to provide evidence that stratospheric material reached the surface, but these analyses must be accompanied by robust model performance evaluations that support their use for this purpose. There are a number of different potential uses of modeling from linking model estimates to meteorological features, to more sophisticated approaches like tracer modeling or source apportionment. Figure 7b shows the lowest layer ozone outputs from the RAQMS model around noon local time on April 22nd. In the context of other material presented earlier, the coincident nature of the high model ozone plume from WY to CO and into NM with meteorological conditions suggestive of a descending streamer of stratospheric air provides additional evidence of an exceptional event.

Figure 7b. RAQMS-estimated ozone near the surface at 1800Z on April 22, 2017



3.5 Differing Levels of Analyses within Tier 1 and Tier 2 Demonstrations

More complex relationships between the subject stratospheric intrusion and the influenced ozone concentrations will require additional detail to satisfy the clear causal relationship element (*i.e.*, a Tier 2 demonstration). This additional evidence can either show the relative contribution estimates to the exceedance from local and transported anthropogenic pollutants compared to the intrusion contribution (*i.e.*, quantification and apportionment) or show that meteorological conditions were not conducive to local photochemical production of ozone and that the demonstrated intrusion best explains the elevated ozone concentration(s). The EPA anticipates that Tier 2 demonstrations would build upon the analyses prepared for Tier 1 demonstrations with the potential approaches described in this section. The EPA does not expect an air agency to prepare all identified analyses, but only those that contribute to understanding the relationship between the event and the measured exceedance. As with all intended exceptional events demonstrations, the submitting air agency and the EPA regional office should discuss the appropriate level of evidence during the Initial Notification process.

There is no rigid set of rules as to which specific analytical elements will be needed to adequately demonstrate an exceptional stratospheric ozone event, as each case is unique. Table 3 provides a checklist of possible analyses that could support the demonstration of a stratospheric event. Other assessments not specifically mentioned in this guidance can also be shown to be valuable. The final rubric for an approvable demonstration is one that builds a consistent analytical narrative that shows stratospheric air entered the FT, was advected down to the surface, and subsequently caused an ozone exceedance at the surface.

3.6 Example Conclusion Statement for the Clear Causal Relationship Criterion

Air agencies should provide a case-appropriate combination of the kinds of evidence and analyses identified in sections 2 and 3 of this guidance and construct a descriptive narrative that supports the existence of a clear causal relationship between the stratospheric intrusion event and the monitored ozone exceedance. This portion of the demonstration should conclude with a statement similar to the language below:

"Based on the evidence, including comparisons and analyses, provided in [*reference the clear causal section*] of this demonstration, [*Air Agency Name*] has established that a clear causal relationship exists between the stratospheric intrusion event(s), which occurred on [*dates*] in [*location*], and the monitored ozone exceedance on [*dates/time of data requested for exclusion or reference to summary table in demonstration*]. The clear causal relationship evidence also demonstrates that the event affected air quality at the monitor."

Table 3. Potential demonstrative analyses for stratospheric ozone exceptional events

Type of Analysis	Tier 1	Tier 2
Conceptual Model	What conditions generally lead to high ozone in the area?	Same as Tier 1
Historical Comparisons	5 years (or more) of peak daily ozone data with other high event days flagged. Table with percentile ranks of days	Same as Tier 1, plus: Historical diurnal profile comparison
Event Overview	Spatial and temporal depictions of ozone during the event. Description of surface and upper air meteorological conditions during the event.	Same as Tier 1, plus: Begin to establish the complex relationship between the intrusion and eventual impact at surface.
Establish stratospheric intrusion	(1 of following is sufficient) • Water vapor imagery • Total ozone column • Simple met model evidence	(several of following needed) • Water vapor imagery • Total ozone column • Rigorous met model evidence
Establish stratospheric air reached surface	(1-2 of following is sufficient) • Rawinsonde data • Met model cross-sections • Trajectory models	(several of following needed) • Rawinsonde data (multiple sites) • LIDAR, tower, aircraft? • Detailed met model cross-sections (multiple variables) • Trajectory models (multiple)
Impacts at the surface	(1 of following is sufficient) • Coincidence between high ozone and met/AQ conditions characteristic of stratospheric intrusions • Summary narrative	(several of following needed) • Coincidence between high ozone and met/AQ conditions characteristic of stratospheric intrusions • Matching day analyses • Model evidence of impacts • Summary narrative

4. Other Required Elements of the Exceptional Event Rule

4.1. Caused by Human Activity that is Unlikely to Recur at a Particular Location or a Natural Event

According to the CAA and the 2016 Exceptional Events Rule, an exceptional event must be "an event caused by human activity that is unlikely to recur at a particular location *or* a natural event." (Emphasis added.) As noted in the preamble to the 2016 Exceptional Events Rule, "[i]n some cases, such as stratospheric ozone intrusions or volcanic eruptions, the EPA recognizes that human activity plays no role in the magnitude of emissions or level of air pollution that occurs" and, therefore, these events are purely natural. And, as defined in the 2016 Exceptional Events Rule, a natural event means "an event and its resulting emissions, *which may recur*, in which human activity plays little or no direct causal role." (Emphasis added.) Thus, treating (recurring) stratospheric intrusions as natural events is consistent with the CAA and the 2016 Exceptional Events Rule, and minimal documentation is needed to meet this element. Air agencies should address the "human activity that is unlikely to recur at a particular location or a natural event" element with a statement similar to the following:

"The Exceptional Events Rule states that a '[n]atural event, which may recur, is one in which human activity plays little or no direct causal role.' Therefore, stratospheric intrusions that cause monitored ambient ozone exceedances or violations are considered to be natural exceptional events. [*Air Agency Name*] has shown through the analyses provided in [*reference the clear causal section*] of this demonstration that the subject stratospheric intrusion caused each of the identified exceedances. Through these analyses and the fact that stratospheric intrusions are purely natural, the [*Air Agency Name*] has satisfied the 'human activity that is unlikely to recur at a particular location or a natural event' element of 40 CFR 50.14(c)(3)."

4.2 Not Reasonably Controllable or Preventable

According to the CAA and the 2016 Exceptional Events Rule, an exceptional event must be "not reasonably controllable or preventable." The preamble to the 2016 Exceptional Events Rule clarifies that the EPA interprets this requirement to contain two factors: the event must be both not reasonably controllable *and* not reasonably preventable at the time the event occurred. This requirement applies to both natural events and events caused by human activities, however it is presumptively assumed that stratospheric intrusions are natural events of a character that cannot be prevented or controlled and thus satisfy both factors of the "not reasonably controllable or preventable" element. Air agencies should address the "not reasonably controllable or preventable" element with a statement similar to the following:

"The documentation provided in [*reference the clear causal section*] of this demonstration shows that the subject stratospheric intrusion caused each of the identified exceedances. Through these analyses and the fact that stratospheric intrusions are purely natural events that cannot be prevented or controlled, [*Air Agency Name*] has satisfied the 'not reasonably controllable or preventable' criterion."

5. Public Comment Process

In addition to providing a conceptual model and evidence to support the 2016 Exceptional Events Rule elements, air agencies "must document [in their exceptional events demonstration] that the public comment process was followed" according to 40 CFR §50.14(c)(3)(v). Air agencies should include in their exceptional events demonstration the details of the public comment process including newspaper listings, website postings, and/or places (library, agency office) where a hardcopy was available. The agency should also include in the demonstration any comments received and the agency's responses to those public comments.

References

Camalier, L., et al (2007). “The effects of meteorology on ozone in urban areas and their use in assessing ozone trends.” Atmospheric Environment, 41, 7127-7137.

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